XXIII.

CONTRIBUTIONS FROM THE PHYSICAL LABORATORY OF THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

XXVIII. — THE EFFICIENCY OF SMALL ELECTRO-MOTORS.

By H. E. H. Clifford.

Presented by Charles R. Cross, March 9, 1887.

The following tests of electro-motors are presented as giving a good example of the efficiency of some of the smaller motors in use at the present day. They have been exclusively devoted to the determination of efficiencies, the subjects of governing and of smoothness of running under different loads being left out of consideration. The only other series of tests which has been published in this country, so far as I have been able to learn, is that made on motors and dynamos at the International Electrical Exhibition held at Philadelphia in 1884.*

The tests have been carried on in the Physical Laboratory of the Massachusetts Institute of Technology during the years 1885–86, by Messrs. F. A. Pickernell, H. G. Pratt, D. P. Bartlett, and the writer, students at the Institute.

The number of machines tested was thirteen. I give below their names, together with either a brief description of their peculiarities or a reference to some publication in which they are described.

Griscom. — S. P. Thompson's Dynamo-Electric Machinery, 2d ed., p. 429.

Ayrton and Perry. — Ibid., p. 432.

Gramme "Machine à petite lumière." — Ibid., p. 120.

Gramme Magneto. — Ibid., p. 117.

Thompson. — Ibid., 1st ed. p. 354.

Deprez. — Prescott's Dynamo-Electricity, p. 707.

Monarch. — An electro-magnet revolving within a ring-shaped electro-magnet making use of consequent poles. The ordinary split-ring commutator is used.

---

* Report of Examiners of Section XXIX. Supplement to the Journal of the Franklin Institute, March, 1886.

Cleveland. — The armature made up of two shuttle-wound armatures mounted on the same shaft but placed at right angles to each other. This armature revolves in a strong field produced by two field magnets, wound so as to have consequent poles at their middle. Instead of brushes, four anti-friction rollers are used in connection with a four-part commutator. The pressure of these rollers is adjusted by springs.

Model Edison Dynamo. — A miniature machine of the Edison pattern, but series-wound instead of shunt-wound.

Diehl. — The field magnets hinged at the yoke so that the distance of the pole pieces from the armature is capable of adjustment, and the armature made up of two Siemens shuttle-wound armatures at right angles to each other on the same shaft. The motor is shunt-wound. Two sizes were tested.

Hill. — The field magnets are placed below the armature, which revolves between cast-iron pole pieces. The armature consists of a series of eight spools of wire arranged in couples, the axes of adjacent couples being at right angles to each other. The motor is series-wound. Two sizes were tested.

The efficiency of a motor is equal to the horse-power delivered, divided by the rate of consumption of electrical energy by the motor; that is, if H. P. = horse-power delivered, C = current in ampères, and E = electro-motive force in volts as measured at the terminals of the machine, efficiency $= \frac{\text{H. P.}}{\frac{C\,E}{746}}$.

The instruments used in the determination of C and E were Sir William Thomson's current and potential galvanometers. These had previously been carefully calibrated and found to be correct to within 0.2% in the positions at which they were used in the tests. In cases where the compensating magnets had to be used, their intensity was carefully determined on each day of use, so that no material error should be introduced from this source. As far as possible, however, the use of the magnets was avoided.

For measuring the power given out by the smaller motors a raw-hide belt or a cotton cord was passed completely around a brass pulley on the motor shaft, the upper end being attached to a spring balance and the lower to a scale pan. By varying the weight in the scale pan the speed of the motor could be changed. A Chatillon balance weighing to $\frac{1}{2}$ oz. was used. In the tests on the Gramme Magneto and the Gramme "à petite lumière," the machines were placed on a cradle dynamometer, a modification of the form devised by Prof. Brackett of Princeton, and a dynamo machine was used as a friction brake. By

closing the circuit of the dynamo through greater or less resistance, the work done, and consequently the power absorbed by the brake, could be varied.

In testing small motors great care must be taken in measuring the speed accurately. In these tests the speed indicator from a small siren was used. This was connected to the motor by an endless band passing from the pulley on the motor shaft to a pulley of the same diameter on the siren. The power required to run this indicator was excessively slight, and in computing the work done was neglected. The slip of the belt was negligible as shown by numerous tests. With the Magneto and Gramme "à petite lumière" a continuously recording engine counter was used connected to the motor by means of a flexible spiral spring.

The following table gives in parallel columns the name of the motor tested, the current in ampères, the electromotive force in volts at the motor terminals, the activity in horse-power, the maximum efficiency, and the speed for maximum efficiency in revolutions per minute.

TABLE I.

Name of Motor.	C.	E. M. F.	H. P.	Maximum Efficiency.	Speed.
				%	
Griscom	3.94	6.74	.006	17.0	1400
Ayrton & Perry	14.40	11.10	.082	38.4	831
Gramme "à petite lumière"	5.29	157.60	.945	84.5	2227
Magneto Gramme. . . .	12.60	27.40	.138	29.8	2067
Thompson	4.90	8.50	.012	21.7	2370
Deprez	4.74	10.40	.011	16.6	2140
Monarch	4.85	5.78	.004	10.1	578
Cleveland	6.78	12.00	.054	49.8	1360
Model Edison	0.82	90.50	.051	51.4	4065
Diehl 1	7.65	16.50	.021	12.3	4180
Diehl 2	6.12	15.10	.031	24.9	2480
Hill 1	4.77	10.30	.010	14.8	2036
Hill 2	5.04	15.10	.032	31.6	3030

The table below gives the tests in full made on the model Edison dynamo, and illustrates very well the relation of speed and efficiency.

This machine is built somewhat after the style of the old Edison Z machine. It is series-wound and has about the resistance (hot) of an Edison incandescent lamp, old style. The dynamo is an exceedingly neat and smooth running machine. The motor runs without vibration and with no sparking, and heats up but very little even at the highest speed. It has been run for two minutes at a speed of 10,000 revolutions per minute. The great speed here obtained by such simple means, together with the readiness with which it can be varied within wide limits, indicates the availability of such a motor in any physical experiments in which a great speed of revolution is needed, as in studies of the velocity of light, the duration of the electric spark, etc.

TABLE II.

Revolutions per Minute.	Electromotive Force in Volts.	Current in Ampères.	Horse-Power put in.	Horse-Power taken out.	Efficiency. Per Cent.
1715	75.8	1.050	.1070	.0278	26.0
1934	75.6	0.987	.1000	.0290	29.0
2372	77.4	0.942	.0978	.0320	32.7
2414	75.6	0.892	.0904	.0306	33.6
2748	75.6	0.835	.0846	.0312	36.9
2895	75.6	0.807	.0817	.0310	38.0
3085	89.8	0.990	.1192	.0462	38.8
3136	76.4	0.795	.0814	.0311	38.2
3200	90.2	0.960	.1160	.0448	38.6
3234	78.0	0.803	.0840	.0328	39.1
3722	76.4	0.685	.0702	.0291	41.5
3750	91.9	0.890	.1100	.0466	42.6
3957	98.8	0.940	.1246	.0544	43.7
3992	91.9	0.840	.1035	.0454	43.8
4065	90.5	0.820	.0995	.0512	51.4
4284	98.8	0.875	.1160	.0533	45.9
4310	90.7	0.780	.0948	.0426	45.0
4352	98.6	0.850	.1124	.0516	45.9
4860	96.6	0.750	.0971	.0437	45.0
4910	98.8	0.775	.1027	.0490	47.7
4922	100.0	0.812	.1094	.0519	47.5
4975	96.4	0.720	.0930	.0399	42.9
5050	95.8	0.690	.0886	.0376	42.4
5640	96.0	0.690	.0888	.0388	43.7
5870	95.8	0.660	.0847	.0365	43.1
6100	95.3	0.610	.0779	.0299	38.4
6130	95.9	0.630	.0810	.0321	39.7
6206	95.5	0.620	.0794	.0315	39.7

One of the chief advantages derived from the use of electro-motors is the small weight per horse-power developed. The motors which we have tested, with one exception, the Gramme "Machine à petite lumière," have been intended for doing very light work, and the efficiency exhibited is not of course nearly as high as would be shown

with larger machines. Activities ranging from 1.31 horse-power to .004 horse-power have been obtained with efficiencies varying from 84.5% to 10.1%. Professors Ayrton and Perry in their paper on "Electro-Motors and their Government," (Journal of Society of Telegraph Engineers, 1883,) state that motors may be constructed to deliver one horse-power per one hundred pounds of dead weight. Table III. shows the horse-power per pound weight of the various motors tested and in no case does it rise as high as .01 of a horse-power. Their own motor, as will be seen by referring to the table, gives but .0045 of a horse-power per pound of dead weight. In the most efficient machine tested, the horse-power delivered per 100 lb. dead weight of machine falls a little short of .8 of a horse-power. I think that for moderately small motors about 300 lb. per horse-power would be a closer figure, although with larger motors this would of course be considerably reduced.

TABLE III.

Name of Motor.	Weight in Pounds.	Maximum Horse-Power delivered.	Horse-Power per Pound Weight.
Griscom	2.80	.0202	.0072
Ayrton and Perry	39.00	.1738	.0045
Gramme "à petite lumière"	172.00	1.3160	.0077
Magneto Gramme	70.00	.1512	.0022
Thompson	6.30	.0138	.0022
Deprez	9.60	.0138	.0015
Monarch	6.10	.0041	.0007
Cleveland	18.50	.1290	.0032
Model Edison	15.25	.0544	.0036
Diehl 1	9.50	.0209	.0022
Diehl 2	20.00	.0309	.0015
Hill 1	7.00	.0120	.0017
Hill 2	16.00	.0374	.0023

Rogers Laboratory of Physics, March, 1887.